Evaluation of Energyconcepts for Office Buildings

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Abstract
"Glass façades" have become a synonym for innovative office buildings in Germany over the last 10 years. Since almost no reliable results of measurement and verification have been made public on the performance of these buildings – often very prominent company headquarters – an expert and public discussion arouse as to whether these buildings can operate energy efficiently or if they can provide for a good user comfort at all.
Therefore the IGS – Institute for Building and Solar Technology started the EVA-project to evaluate the performance of a typical sample of five of these buildings as well as a sample of conventional office buildings.
This paper surveys the projects methodologies and buildings. Results of the first phase that documented the participating buildings and analysed existing data on energy consumption suggest that glassed office buildings do not generally have a significantly higher energy consumption than regular office buildings.

Introduction
Over the last 10 years, some research projects analysing the energy efficiency and user comfort of office buildings have been carried out in Germany with different objectives. In 1999, ages GmbH created an energy consumption database of about 1.700 mostly public buildings [1] similar to the Swiss study of 100 office buildings published in 1999 [2]. These studies provided very good data on a large sample of buildings but no information on individual buildings.
In contrast, the individual analysis of buildings was the object of the research programs enerkenn [3] and solarbau [4], both supported by the Federal Ministry of Labor and Economics. Within solarbau, the design phase and the first two years of operation of more than 20 low energy buildings have been analysed in detail aiming at a target value of 100 $kWh/(m^2_{NGF}a)$[1] of primary energy demand and a good thermal comfort without the use of chillers.
In enerkenn 9 office buildings of *German Railways*, all built between 1995 and 2002, were analysed with the same focus on energy consumption and thermal user comfort.
6 buildings that were examined within an EG-Audit in 1996 [5] showed an average consumption of 543 $kWh/(m^2_{NGF}a)$. A study of the city of Frankfurt in 2002 on 13 office buildings [6] reported a similar average consumption of primary energy of 503 $kWh/(m^2_{NGF}a)$. However the study did not name the buildings nor explain in detail how the analysis was carried out.
Most studies also showed a significant potential for a reduction of energy consumption through the improvement of building operation. The results of these studies were published and are widely noticed within the scientific community.
In contrast to these studies, public attention and discussion focused on a special type of innovative office buildings. Their obvious and largly recognized attribute were almost completely glassed façades, although most of these buildings also had sophisticated HVAC- concepts. Prominent company headquarters like the RWE Tower, Essen 1997, by architect Christoph Ingenhoven or the Nord LB, Hannover 2002, by architect Günther Behnisch, were widely published especially in architectural and engineering journals being described as "ecologic high rise building" [7], the "maximum that can be accomplished in ambitious office buildings today" [8] or – according to other masterpieces of art – even as "well tempered architecture" [9].
As a response to this architectural "fashion" critics argued that these "so-called" innovative buildings were neither more energy efficient nor more comfortable than buildings with less glassed façades but instead had problems with high indoor air temperature and energy consumption caused by the glassed façades. Gertis [10] had summarized the controversy in 1999 with respect to glass double façades concluding that measurement and verification were necessary for a profound judgement instead of descriptive and uncritical "stories" in architectural journals. Only few projects followed his suggestion. Among these is a study on 4 glass double façades evaluating their effect on heat consumption and thermal user comfort [11].

[1] NGF: heated net floor area

In 2004, the discussion culminated when it made it into Germany's most important news magazine "Der Spiegel" publishing an article on "Life in the Headlock" [12] and the allegedly failed experiment on glassed office buildings. The article was typical for the ongoing public and expert discussion as it quoted several "experiences" and "opinions". At the same time the author admitted that there is a "wall of silence" and a complete lack of information about the performance of these buildings.

Despite these critics, "glass buildings" had become a synonym for innovative buildings and had been trend-setting for German architecture. Pottgiesser [13] reported on more than 200 buildings built between 1990 and 2003 using glass double façades. Measurement and verification of their performance were urgently necessary. Therefore IGS started EVA in 2004 funded by the Federal Ministry of Labor and Economics, E.ON Energie AG and participating companies.

Object

A major objective of EVA is to verify wether the "so-called" innovative office buildings were equally or more energy efficient and comfortable as conventional buildings or if they indeed were energy wasting "headlocks".
A sample of buildings was to be analysed by measurement and verification of energy consumption and user comfort to answer the following questions:

1. Are the "prominent" innovative glass-buildings built, used and operated in the originally intended way?
2. Do they meet the target values of the original design or reference values for energy efficiency and user comfort or are there (positive or negative) deviations?
3. If deviations are detected, what are their causes and how can buildings and operation be improved?

The answers will contribute to a more substantial and less polemic public discussion of innovative office buildings and glass façades.

Buildings

The sample of 19 office buildings was put together during a 18-month acquisitioning campaign in which it proved to be very difficult to convince companies to open their buildings for research. When the project started, the sample consisted of three different types of buildings:

- 5 typical glass buildings that had been explicitly designed as "innovative" buildings with glass façades
- 12 "conventional" buildings without the explicit object of being innovative or energy efficient as reference for the regular building standard
- 2 low energy office buildings that had already participated in the solarbau-project for which the performance should be verified in a long-term monitoring

All buildings had been built between 1993 and 2003. The sample consists of buildings with a low (heating, natural ventilation/windows), middle (heating, mechanical ventilation) and high standard of technical installation (mechanical ventilation, de-/humidification, cooling). Table 1 shows the 5 innovative buildings with features of the energy concepts. No. 6 and 7 are the solarbau buildings.

1. Nord LB Hannover
Hannover, 2002

Architects: Behnisch, Behnisch u. Partner
Concept: glass double façade, concrete slab cooling, energy piles, absorption chillers

2. Finanz IT
Hannover, 1999

Architects: Hascher Jehle, Berlin
Concept: large glassed atrium, concrete slab cooling, natural ventilation

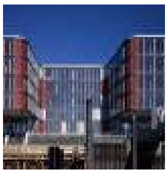	**3. Rickmers Reederei** Hamburg, 2002	*Architects:* BRT Architekten, Hamburg Concept: glass double façade, concrete slab cooling, ventilation system with façade integrated air intake, energy piles, heat pump
	**4. Braun GmbH** Kronsberg/Taunus, 2000	*Architects:* Schneider+Schumacher, Berlin Concept: glass double façade, atrium with openable foil-roof, concrete slab cooling
	**5. LBS-Nord** Hannover, 2001	*Architects:* PSP Pysall-Stahrenberg u. Partner Concept: large glassed atrium, ground channel for supply air
	**6. EnergieForum** Berlin, 2003	*Architects:* BRT Architekten, Hamburg Concept: large glassed atrium, concrete slab cooling, natural ventilation, energy piles, heat pump
	**7.Neubau Informatikzentrum** Braunschweig, 2001	*Architects:* PSP, Braunschweig large glassed atrium, natural ventilation, ground channel for supply air, electrochromatic glass

Table 1 List of "innovative" and solarbau buildings

Methods

The project started with a comprehensive documentation of all 19 participating buildings including:

1. building geometry and envelope
2. HVAC concepts and systems
3. legal and service situation of buildings (ownership, facility management)
4. general objects (innovation, ecology, corporate identity) and target values
5. regular measurements & verification actions
6. user comfort as seen by the management responsible for building operation
7. existing data on energy consumption (i.e. energy bills or other documentation)
8. building costs for construction and technical installations

In addition, an individual evaluation concept was created for detailed analysis of energy consumption and user comfort. It was originally intended to reduce the sample after this phase to 10 buildings with good premises for evaluation and support from the participating company. Finally – after the first phase had been carried out – the sample was only reduced to 14 buildings including all glass buildings.

The second phase of detailed evaluation has begun building by building since summer 2004. Methodologies are closely linked to the other research projects of the ENOB-program and to

DIN V 18599, the German implementation of the European Performance of Buildings Directive [14]. Table 2 gives an overview of the general evaluation program that will be applied to all buildings.

Aspects	Activities	Evaluation
Over all Energy consumption	Monitoring of overall energy consumption: o power measurement for heat and electrical energy o duration: 1 year o time step: 15 minutes according to VDI 3807 [15].	Comparison of o consumption and peak loads with general regulation (WSchVo `95 [16]) and results form other ENOB-projects o consumption with reference buildings and DIN V 18599
Electrical energy		
Subsystem ventilation	Documentation of existing design of HVAC systems	Comparison with the intended concept
	Analysis of air exchange rate with SF6 tracer gas where of special interest for the building concept	Comparison with the target values of concept and HVAC system design
	Calculation of energy demand according to LEE [17] using o Short term measurements of consumption/electrical load o Data of building management systems (time of operation, air temperature etc.)	Comparison with o target values of LEE o target values of DIN V 18599 o results of other ENOB-projects
	Calculation of energy saving potential and optimization where possible	According i.e. to VDI 2067 [18]
Subsystem artificial lighting	Documentation of existing design of lighting systems	Comparison with the intended concept
	Calculation of energy demand according to LEE using o documentation of installed power o long-term measurement (12 month where possible) o analysis of existing data form building control systems	Comparison with o target values of LEE o target values of DIN V 18599 o results of other ENOB-projects
	Calculation of energy saving potential and optimization where possible	Evaluation according to LEE
Other subsystems	Measurements of consumption of subsystems and other components, especially o chillers o central IT-systems o areas with special uses (kitchen, retail etc.)	Depending on individual building concepts
User comfort	Monitoring in 3-6 rooms: air temperature, humidity, temperature of HVAC-systems in rooms: o long-term measurement (6-12 month) o analysis of existing data form building control systems	Comparison with target values of o building simulations o general regulations (DIN 1946-2 [19], DIN 4108 [20])
	Short term measurements in 4 rooms in winter, spring, summer in the morning/noon/afternoon according to DIN EN 7730 [21]	Comparison with target values of o building simulations o general regulations (DIN EN 7730, DIN 1946-2, DIN 4108)
	Analysis of air exchange rate with SF6-Tracer gas where of special interest for the building concept in typical rooms	Comparison with target values of o building simulations o HVAC-system design o general regulations (DIN 1946-2, DIN 4108)
	Optimization where possible	Evaluation of improvements as described above
User behavior	Documentation of use of window	Comparison with

	o for natural cooling at night o with high ambient temperatures during the day using building control data or measurements	o target values of building simulations and actual use o results of ENOB-projects and reference studies
	Documentation of user interference in use of sun shading: o time of non-function due to wind o time of non-function due to user interference using video/photo-monitoring of façades and data from building management systems	Evaluation of deviations between building simulation and actual use
User Questionnaires	Questionnaires for 50 employees in summer and winter (according to solarbau) on user comfort and behavior This work package will be carried out in cooperation with fbta, TU Karlsruhe. Questionings will not be possible in some of the buildings due to restrictions by owners or users.	Comparison with results of ENOB-projects
	Additional analysis according to individual energy concepts, i.e.: Measurement of air temperature and air exchange rate in glassed atriums	Depending on individual building concepts

Table 2 Methodologies of the evaluation concept

Since work packages are limited by the projects time and financial budget, only a limited number of systems and rooms can be monitored. Especially effects of user behavior, partial occupancy of buildings and malfunction of individual systems might not completely be detected or considered. The systems and rooms to be monitored will therefore be selected regarding any problems known to the operating staff or which have been detected during the first phase.

First Results

Phase 1 has been completed and all buildings have been documented. Although some of these buildings were designed with the explicit target of being energy efficient, there were no corresponding concepts for measurement and verification. Few buildings had some kind of regular report on energy consumption. These reports did not include a verification of target values but only stated consumption data.

In the first phase it was possible to generate values for energy consumption for 16 buildings using existing data. Two buildings did not have the necessary metering devices for the measurement of significant data on the overall energy consumption. One building was not included within comparisons on energy consumption since it contained a significant use for laboratories.

The authors have not jet received permission to publish results for all individual buildings. Therefore Figure 1 shows average values of end energy use and reference values from studies mentioned above.

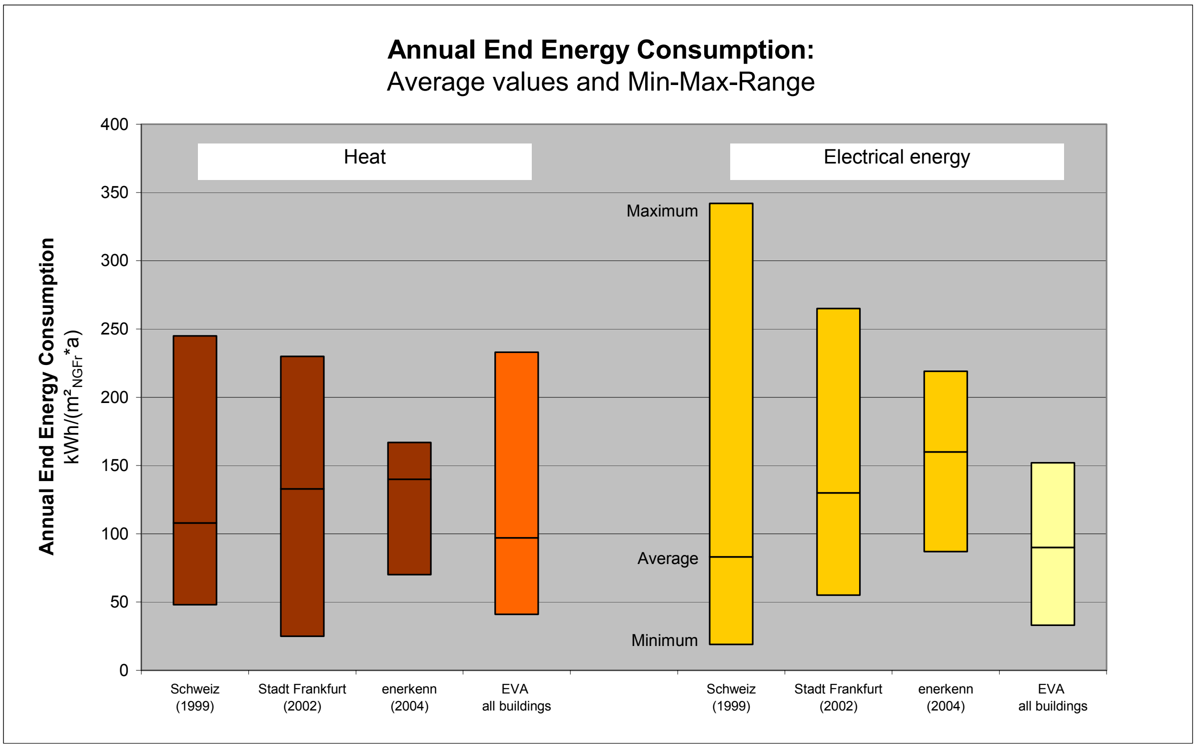

Figure 1 Average and minimum/maximum values for annual end energy consumption of heat and electrical energy for 16 EVA-buildings and reference studies
Reference studies: Schweiz [2], Stadt Frankfurt [6], enerkenn [3]
Schweiz: the maximum value for electrical energy results form a single exceptionally high value
NGF_r: heated net floor area

The EVA buildings have an average heat consumption of 94 kWh/(m^2_{NGFr}a) ranging from 40 to 205 kWh/(m^2_{NGFr}a). Only the values for the heat consumption of two buildings exceed 150 kWh/(m^2_{NGFr}a).
The average consumption of electrical energy is 90 kWh/(m^2_{NGFr}a) with individual values between 35 and 150 kWh/(m^2_{NGFr}a).

The minimum values represent a solarbau building for both heat and electrical energy consumption.

The average values for the consumption of primary energy are shown in Figure 2.

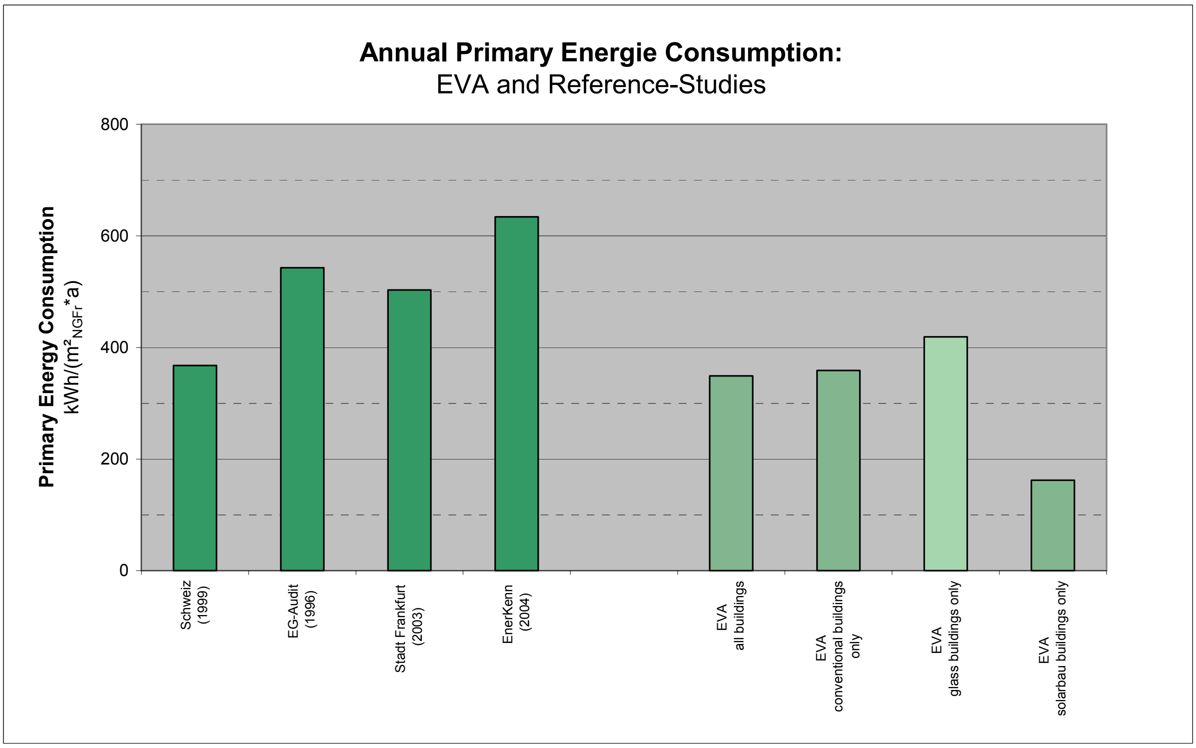

Figure 2 **Average Annual Consumption of Primary Energy for 16 EVA-buildings and Reference-Studies**
Reference studies: Schweiz [2], EG-Audit [5], Stadt Frankfurt [6], enerkenn [3]
EVA glassed buildings includes 4 buildings with existing data

The average consumption of primary energy for all EVA buildings for which data existed is 349 kWh/(m^2_{NGFr}a). This almost equals the average consumption of the Swiss study but is significantly lower than the average of recent studies on German buildings that show values between 500 and 640 kWh/(m^2_{NGFr}a). The EVA average doubles the solarbau value.

The average value for conventional buildings in EVA is 359 kWh/(m^2_{NGFr}a), the one for glass buildings is 419 kWh/(m^2_{NGFr}a), for the solarbau buildings 162 kWh/(m^2_{NGFr}a).
Within the EVA sample, the average consumption of glass buildings is about 16% higher than the average consumption of conventional buildings in EVA but 15-45% lower than the average values indicated by the German reference studies.

Figure 3 shows a comparison of calculated and permissible values for heat demand with the actual annual heat consumption. Data of the existing certificates according to building regulation WSchVo `95 was used as values for heat demand. Although the calculation method of WSchVo '95[2] is not intended to predict energy consumption, the comparison is significant since it defines mandatory permissible values for building parameters relevant for heat consumption.

[2] WSchVo `95 focuses on the building envelope and considers only a fixed air exchange rate of 0,8h^{-1} to calculate heat losses through ventilation.

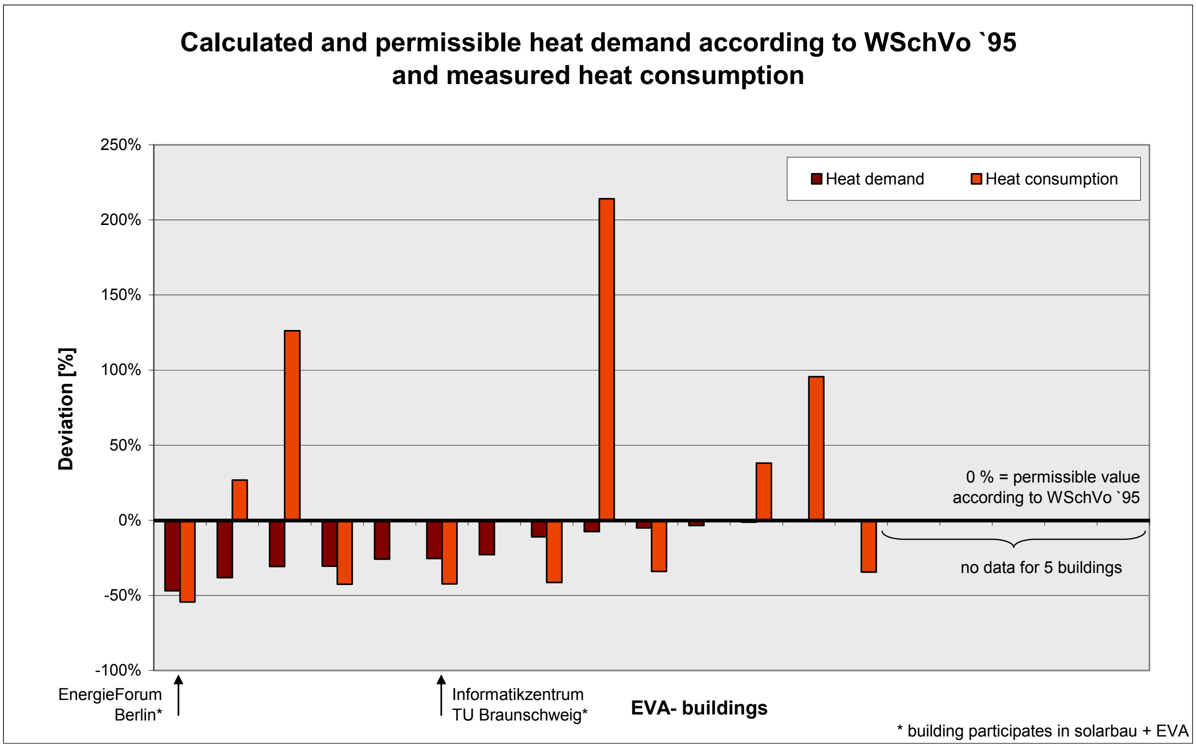

Figure 3 **Calculated and permissible values for heat demand and measured heat consumption for 14 EVA buildings**
Most EVA-buildings have been built according to WSchVo `95. The individual permissible value was set as 0%, the calculated heat demand and consumption is given as deviation to the permissible value.

The comparison of permissible and target values for heat demand with the actual heat consumption shows that, according to the existing building regulation, for most of the buildings a target value was calculated significantly below the limit.
The heat consumption of six buildings equaled the target value or was even lower. Among them were the two buildings of the solarbau project which have been very thoroughly monitored and optimized for two years. Five buildings exceed the permissible values by 25% to more than 200%.

Conclusion and perspective
Most of the buildings – glassed and conventional – do not have an implemented process for measurement and verification of target values. In fact, even the documentation of individual target values turned out to be difficult. Further investigation in the second phase with the design team might add some target values.
The lack of data – already itself an interesting result on the priority of measurement & verification – will in most cases lead to an evaluation comparing measurements with reference studies and target values defined by general building regulations rather than with individual target values.

The first results do not suggest that “so called” glass buildings generally use significantly more energy than conventional buildings. Neither the consumption of heat and electrical energy nor the average consumption of primary energy exceeds the magnitude of reference studies.
However, some buildings of the sample extremely exceed the permissible values according to WSchVo `95. Possible causes may be construction other than designed or malfunction. The large deviations and the fact that the two solarbau-buildings do meet the target values suggest that the deviations are not primarily due to user behavior. Other reasons can be an incorrect certificate or the fact that the calculation method could only inappropriately be applied on these buildings. In any case, the regulation failed to guarantee a low heat consumption. Finding out the reasons will be a task of the second phase.

Monitoring and detailed analysis have started on all buildings. This paper will be followed by reports on individual building evaluations.

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